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AFTAC Project No. VELA/T/0701/B/ASD

LONG-PERIOD SIGNAL SEPARATION EXPERIMENTS

Technical Report No. 6

SEISMIC ARRAY PROCESSING TECHNIQUES

Prepared by

Dr. Chung-yen Ong

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Area Code 214, 238-6521

TEXAS INSTRUMENTS INCORPORATED
Services Group
P. O. Box 5621
Dallas, Texas 75222

Contract No. F33657-70-C-0100
Amount of Contract: $339,052
Beginning 15 July 1969
Ending 14 July 1970

Prepared for

AIR FORCE TECHNICAL APPLICATIONS CENTER
Washington, D. C. 20333

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Nuclear Monitoring Research Office
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15 August 1970

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ABSTRACT

The problem of separating Rayleigh waves from two distinct epicenters received simultaneously was studied. The relations between the target-to-interfering-event (TTIE) ratio and interfering event suppression as well as target event extraction in MCF design were examined. Using the vertical components of the array, the results show that interfering event suppression increases as TTIE ratio increases. For the data recorded at LASA, using a 5-channel, 21-point MCF designed with a TTIE ratio equal to -10 db and -40 db, the interfering event was suppressed by 15.5 db and 22.0 db respectively. There was no significant signal distortion.

The coherence between the vertical and horizontal traces of an individual site was examined, using two UBO samples. Utilizing a 2-channel, 43-point prediction filter, prediction errors of -9.1 db and -16.4 db respectively are shown in the results.

SECTION I

INTRODUCTION

Presented in this report are the results for separating Rayleigh waves from two distinct epicenters received simultaneously by LASA long-period array under the assumption that both events have been detected and their epicenters have been located by other means. The simulation was done by compositing two events from different epicenters. The vertical component of the two events were composited at several different ratios in order to examine the effect of target-to-interfering-event (TTIE) ratio on the interfering event suppression for Wiener signal-extraction multichannel filters. The two events used to form the composite originated in the New Hebrides Island and Hokkaido, Japan. Azimuthal separation between propagation vectors for these two events at LASA was about 55°.

The coherence between vertical and horizontal traces has been studied in this report. The two events used for the experiment were received by UBO and originated in the Soloman Island and Rat Island. A Wiener multichannel prediction filter was designed to predict the vertical trace from two horizontal traces. The mean-square-prediction error was measured.

SECTION II

EVENT SEPARATION USING VERTICAL COMPONENT MCF PROCESSOR

Simulation was accomplished using a synthetic composite event that consisted of the interfering Hokkaido event and the target New Hebrides event. The Ao and C-ring vertical traces from LASA were used for time-domain MCF design. Each trace consisted of 1600 sample points with a sample period of 1 second. For compositing the events, New Hebrides data were scaled down such that the peak power level of the Ao trace was lower than that for the Hokkaido event by 10 db, 26 db, 40 db, and ∞ db, respectively. The composite traces were interpolated by a 6-point Langrange's interpolator and time-shifted to align the target event. The velocity used in calculating time shifts was 3.5 km/sec. In the MCF design, the measured covariance matrix of the composite event was used as the covariance matrix of noise, and the measured correlation function of Ao was used as the signal correlation. The main diagonal of the measured covariance matrix was scaled by 1% for stability and in the Wiener Filter design equations a S/N ratio of 4 was used. In this section, all MCFs are 21 points long.

The designed MCFs were applied to the individual New Hebrides and Hokkaido data sets which were interpolated and time-shifted to align the target event also. The results are shown in Figure II-1.

The interfering event suppression increased as the TTIE ratio increased. With the New Hebrides event 10 db down in the composite event, the MCF can suppress the Hokkaido event 15.53 db down while the Hokkaido event can be suppressed as much as 22.07 db if the composite event consists of the Hokkaido event only. The target event was passed almost without distortion for the MCF designed with the New Hebrides event more than 26 db down in the composite event. A 0.168-db target-event suppression was measured for the case with the New Hebrides event down 10 db. The mean-square-output (MSO) of the MCF and its ratio with the mean-square-value (MSV) of the reference trace Ao are shown in Table II-1. In every case the target waveform was essentially undistorted.

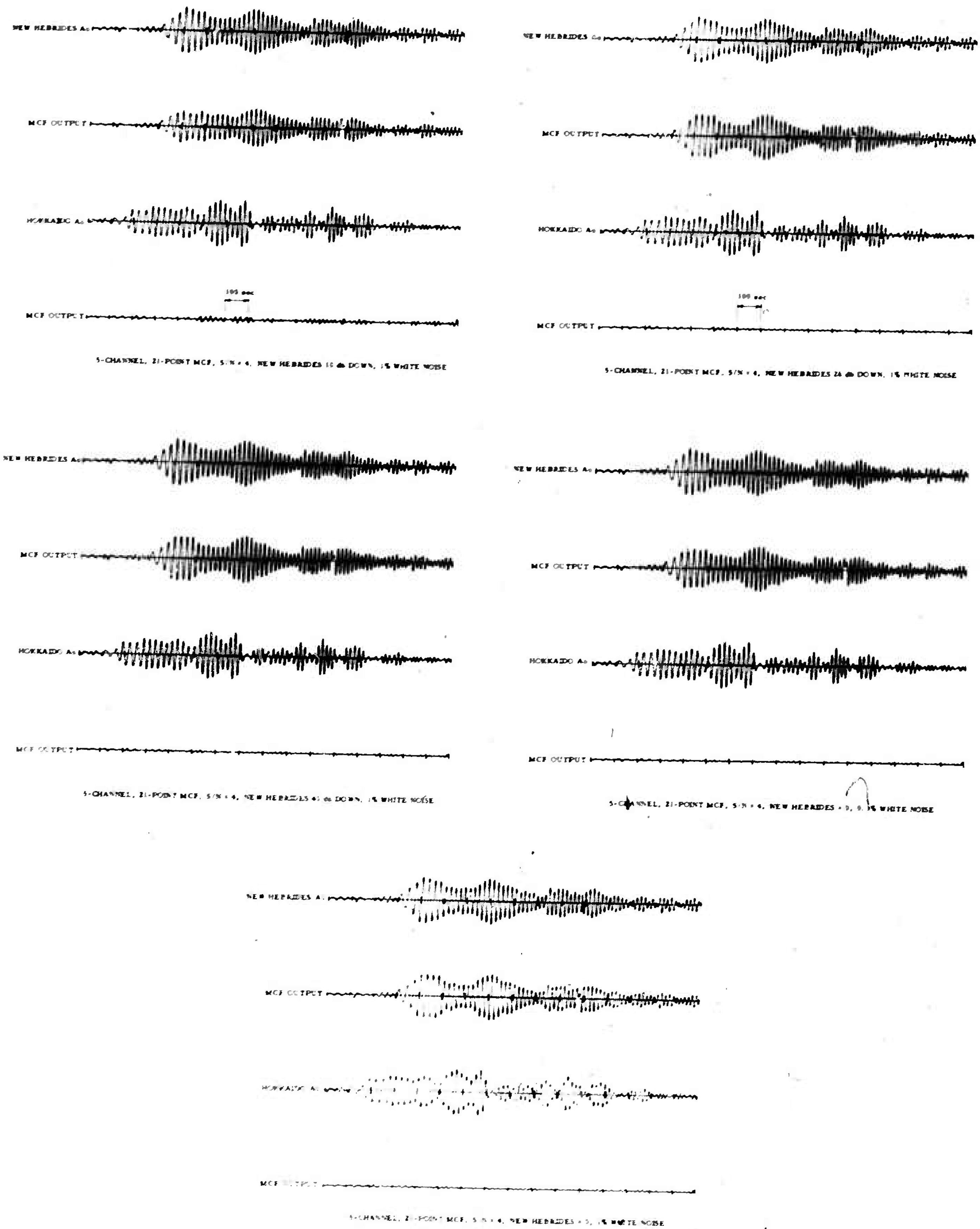

Figure II-1. New Hebrides and Hokkaido MCF Processing Results

The power density spectra (by direct Fourier transform of the time trace) of the MCF outputs along with those of Ao Hokkaido and New Hebrides traces are shown in Figure II-2. Most of the interfering event suppression occurred between 0.03 and 0.07 Hz, where appreciable power exists. The peak value of interfering event suppression was about 24 db (at 0.039 Hz) for the case with the New Hebrides event down 10 db, and 34 db (at 0.042 Hz) for the case without New Hebrides in the composite event.

In order to see the effect of the white noise added in the MCF design, one run was made with 0.3 percent of white noise added to the covariance matrix of noise and with New Hebrides eliminated from the composite event. The results show 1.21 db (average power) better interfering event suppression.

Table II-1

MEAN-SQUARE OUTPUTS OF MCF PROCESSING

MCF Processor	New Hebrides		Hokkaido	
	Mean-Square Output	MSO/MSV of Ao (db)	Mean-Square Output	MSO/MSV of Ao (db)
With New Hebrides 10 db down	8.429×10^4	-0.168	7.519×10^3	-15.53
With New Hebrides 26 db down	1.211×10^5	-0.011	1.848×10^3	-21.61
With New Hebrides 40 db down	1.216×10^5	-0.009	1.688×10^3	-22.00
With New Hebrides ∞ db down	1.212×10^5	-0.010	1.670×10^3	-22.07
With New Hebrides ∞ db down (0.3% Noise)	1.124×10^5	-0.040	1.256×10^3	-23.28
Ao	1.241×10^5		2.656×10^5	

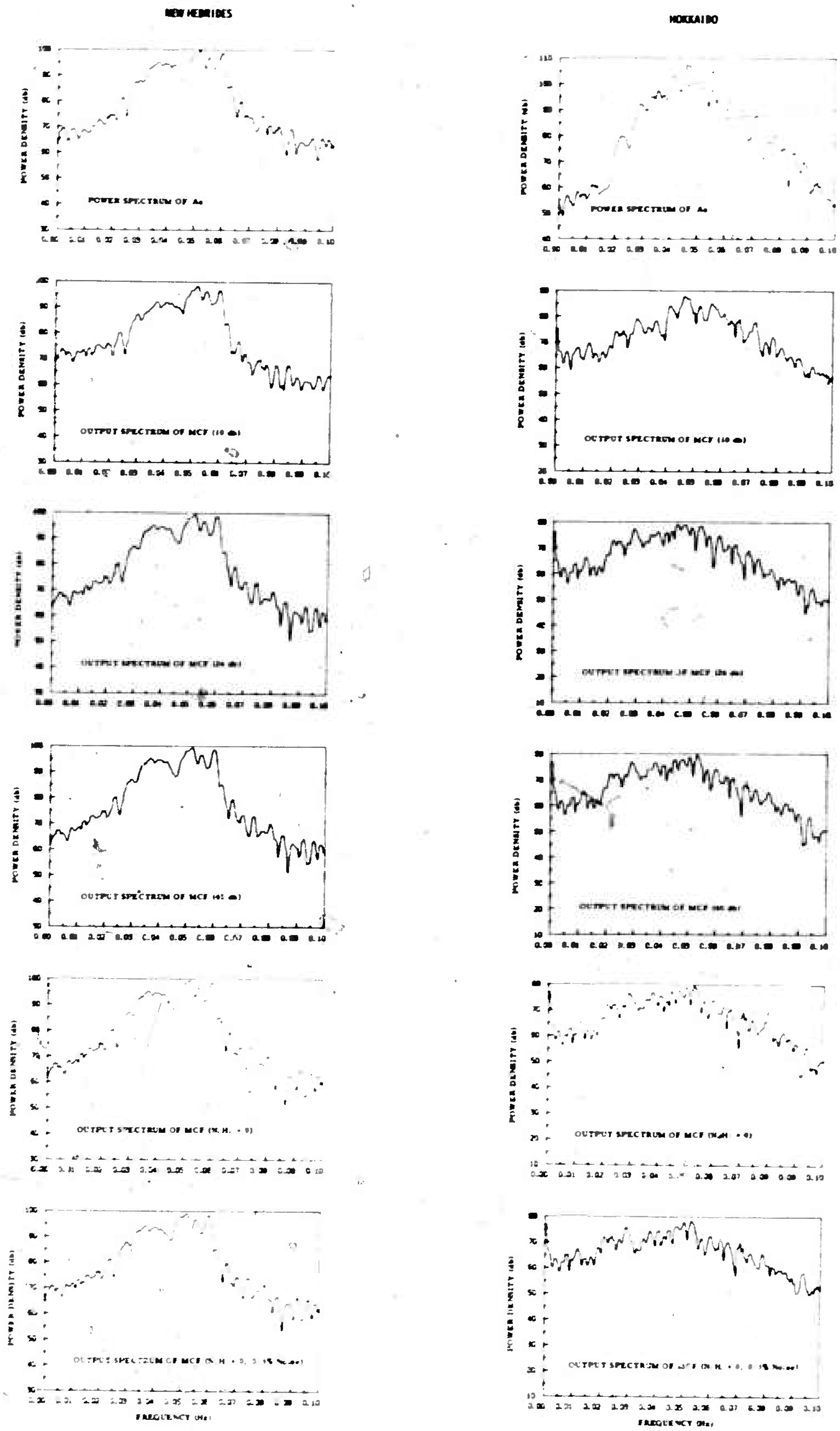

Figure II-2. Power Density Spectra of the MCF Outputs

SECTION III

COHERENCE BETWEEN VERTICAL AND HORIZONTAL COMPONENTS

This section is concerned with efforts made to examine the coherence between vertical and horizontal traces of an individual site by predicting the vertical trace from two horizontal traces. The data used for this study were recorded at UBO and originated in the Rat Island and Soloman Island, respectively. The data were sampled in 1-second periods. UBO is a seven-element array, but only one of the elements was used in the experiment. The vertical and horizontal traces of the two events are shown in Figures III-1 and III-2.

All the prediction filters that were designed are 2-channel and 43 points long, with 0.3 percent of white noise added to the covariance matrix of horizontal traces. For the Soloman Island event, a prediction filter was designed by using all 1000 points of data. The filter output and error traces are shown in Figure III-3. The ratio of mean-square-error (MSE) to MSV of vertical trace is 0.121 (or -9.16 db), which was discouraging. The power density spectrum of the vertical trace and normalized prediction error power density spectrum (normalized by the vertical trace power density) are shown in Figures III-4 and III-5. The smallest prediction error was -15 db at 0.025 - 0.045 Hz range, where appreciable power exists in the vertical trace.

The 500 data points of the Rat Island event were used to design the prediction filter. The results are shown in Figure III-6. The ratio of MSE to MSV of vertical trace is 0.0226 (or -16.43 db), which was encouraging. The power density spectrum of the vertical trace and normalized prediction error power density spectrum are shown in Figures III-7 and III-8. The best prediction error is -23 db at 0.045 Hz, where vertical trace has peak power. This result shows considerable coherence between vertical and horizontal traces.

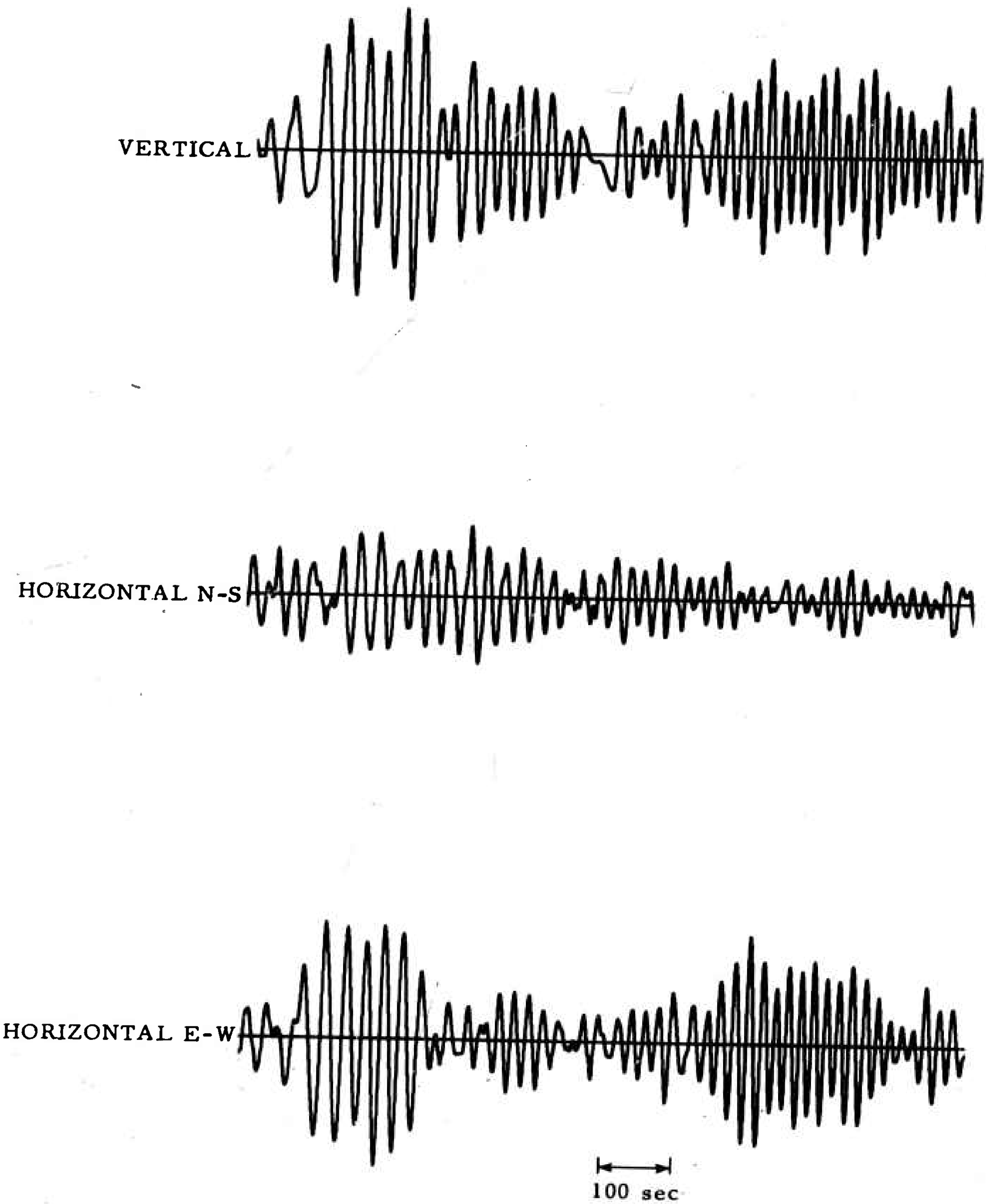

Figure III-1. Soloman Islands Event

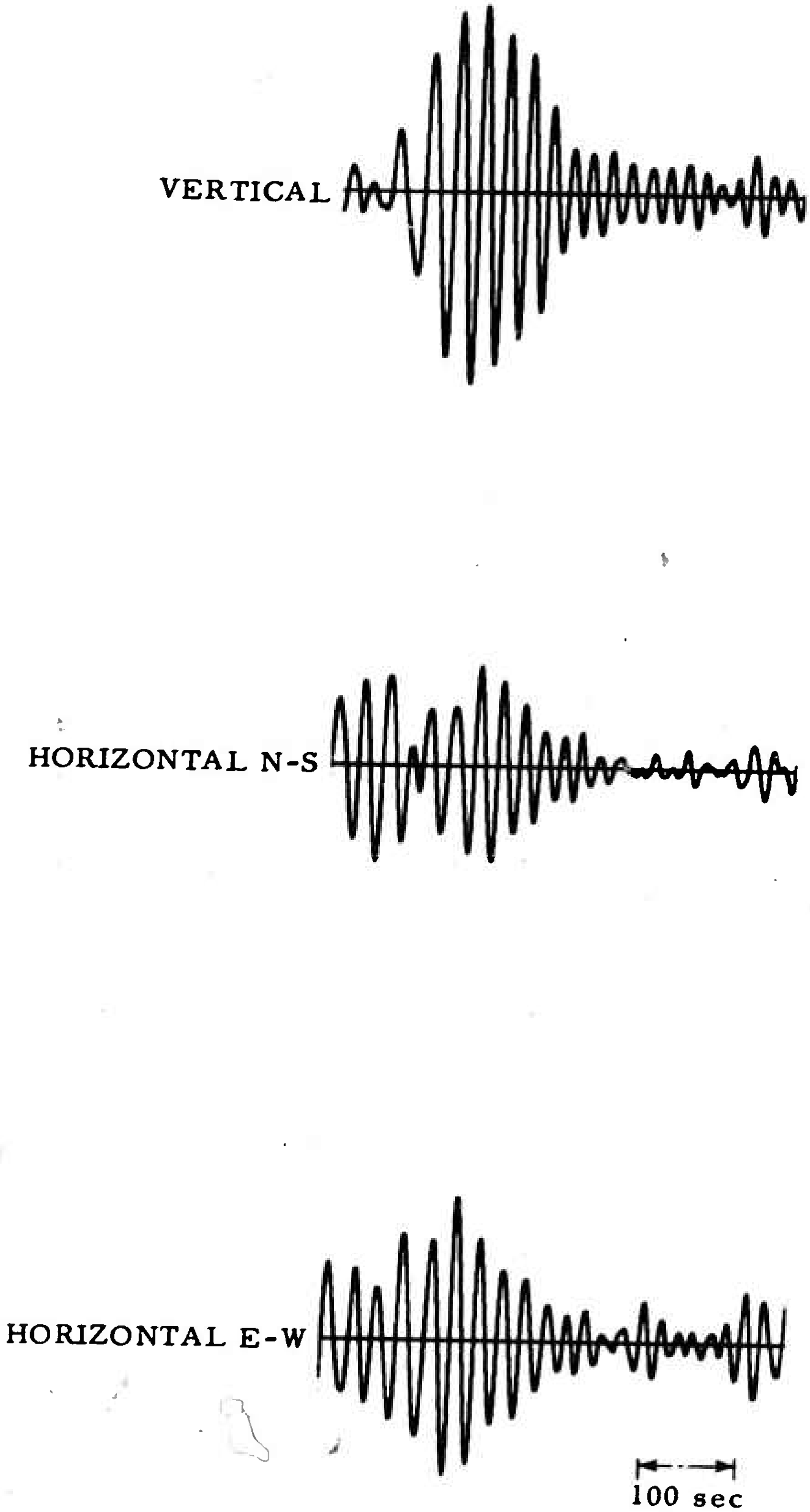

Figure III-2. Rat Island Event

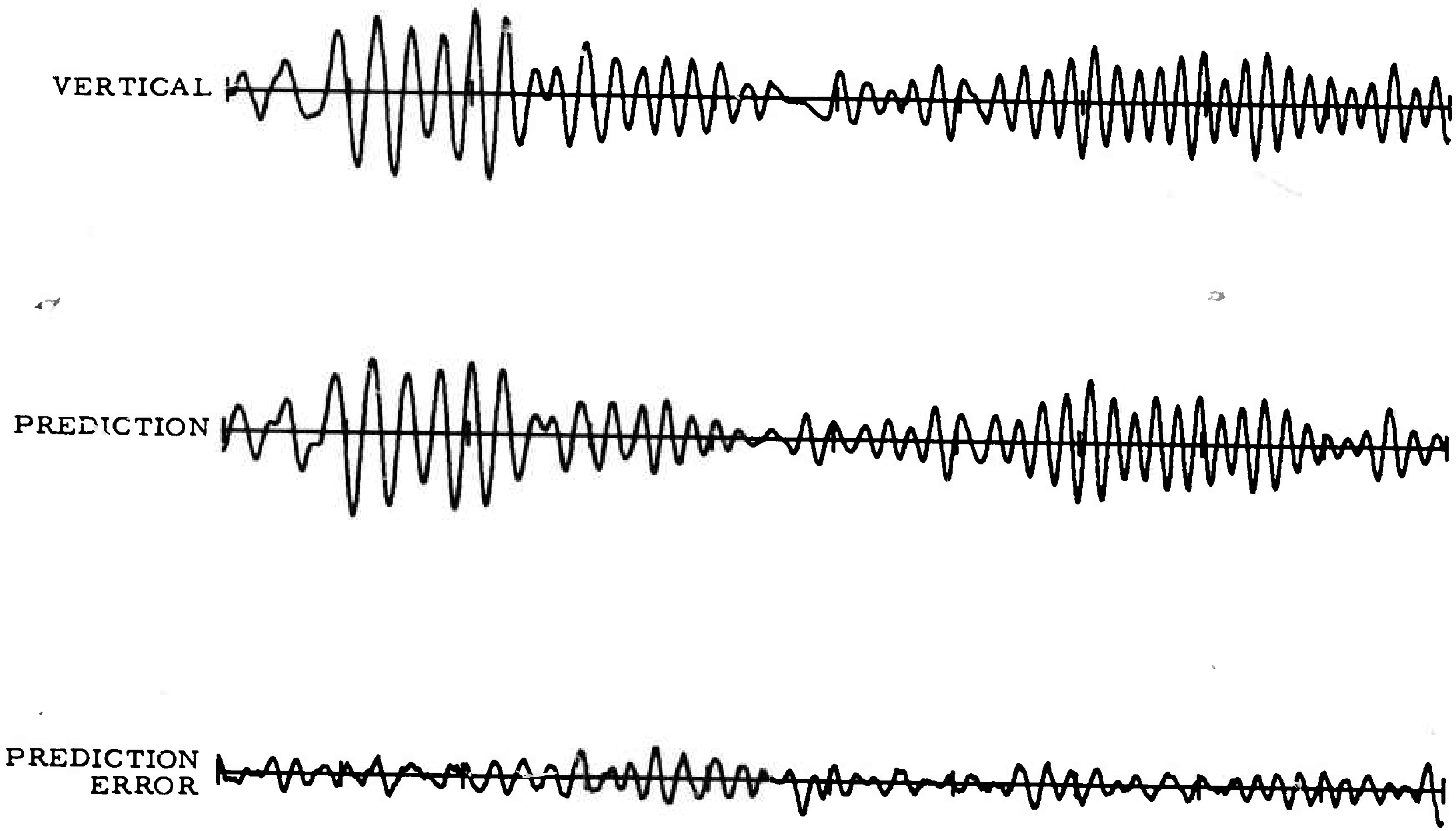

Figure III-3. Soloman Islands Prediction Filter Results

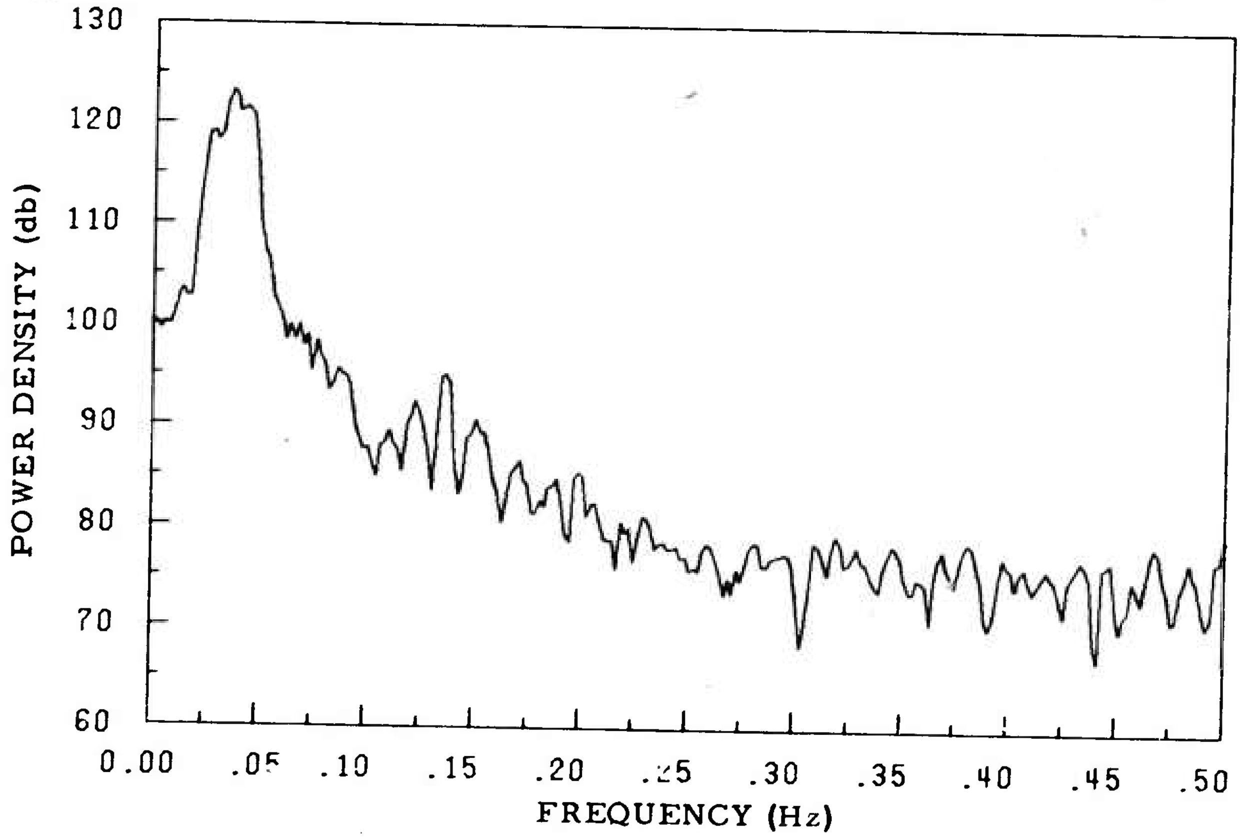

Figure III-4. Power Density Spectrum of Vertical Trace, Soloman Islands

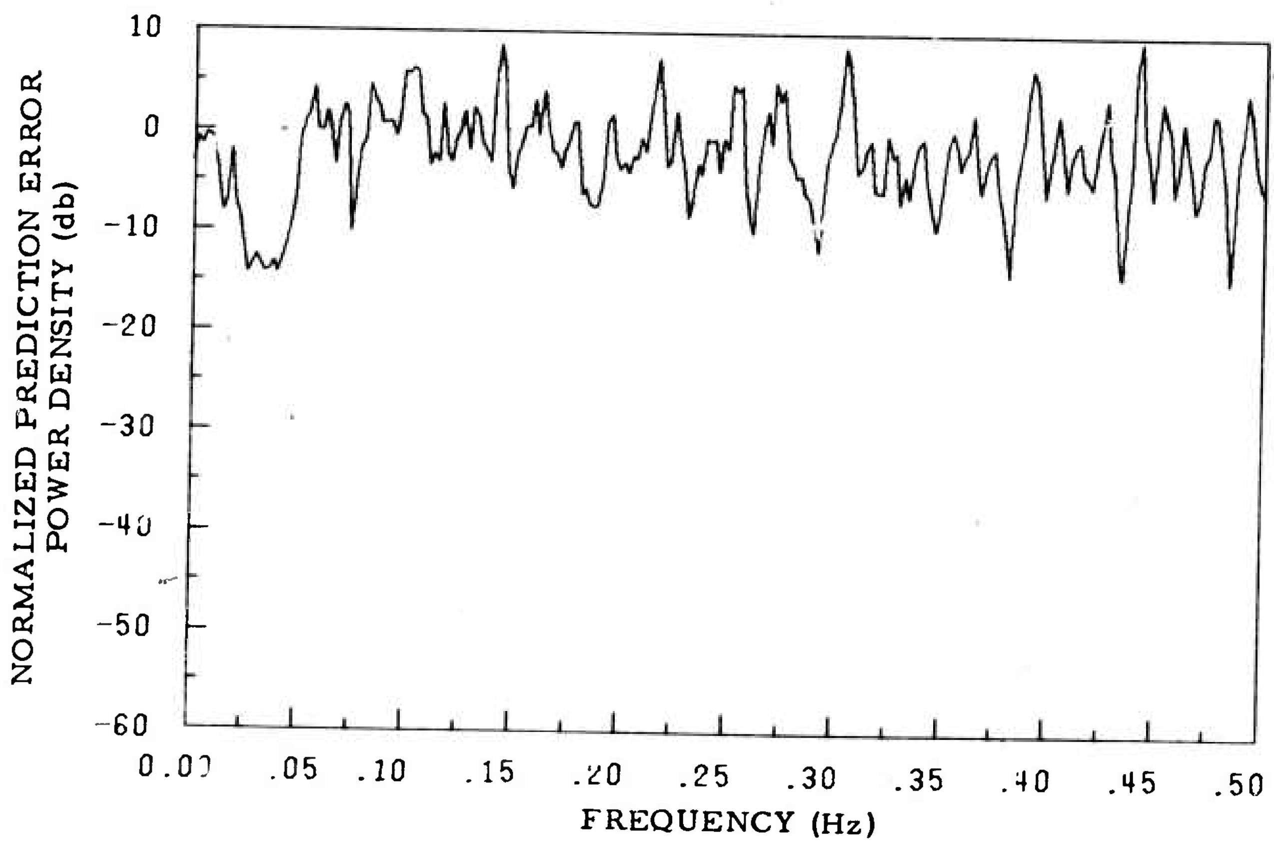

Figure III-5. Normalized Error Power Spectrum
Soloman Islands, Time Gate 0 - 500 sec

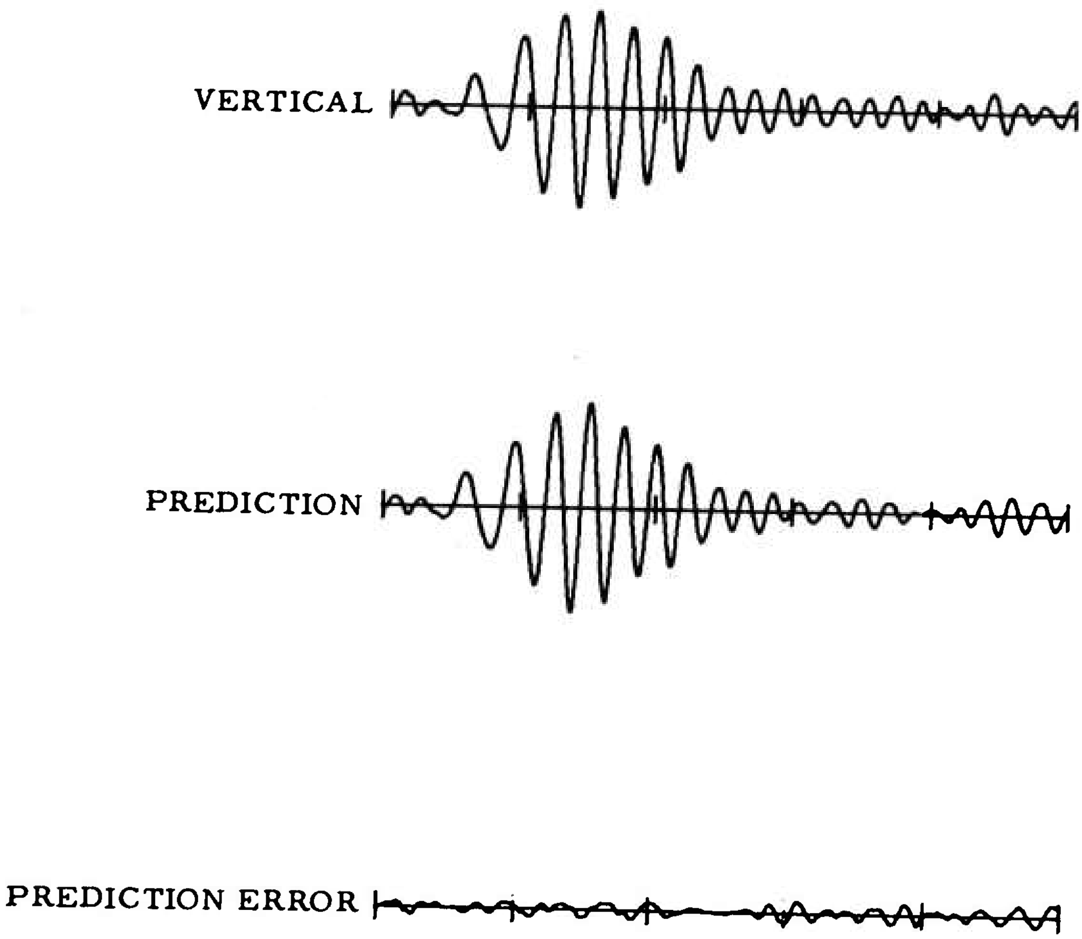

Figure III-6. Rat Island Prediction Filter Results

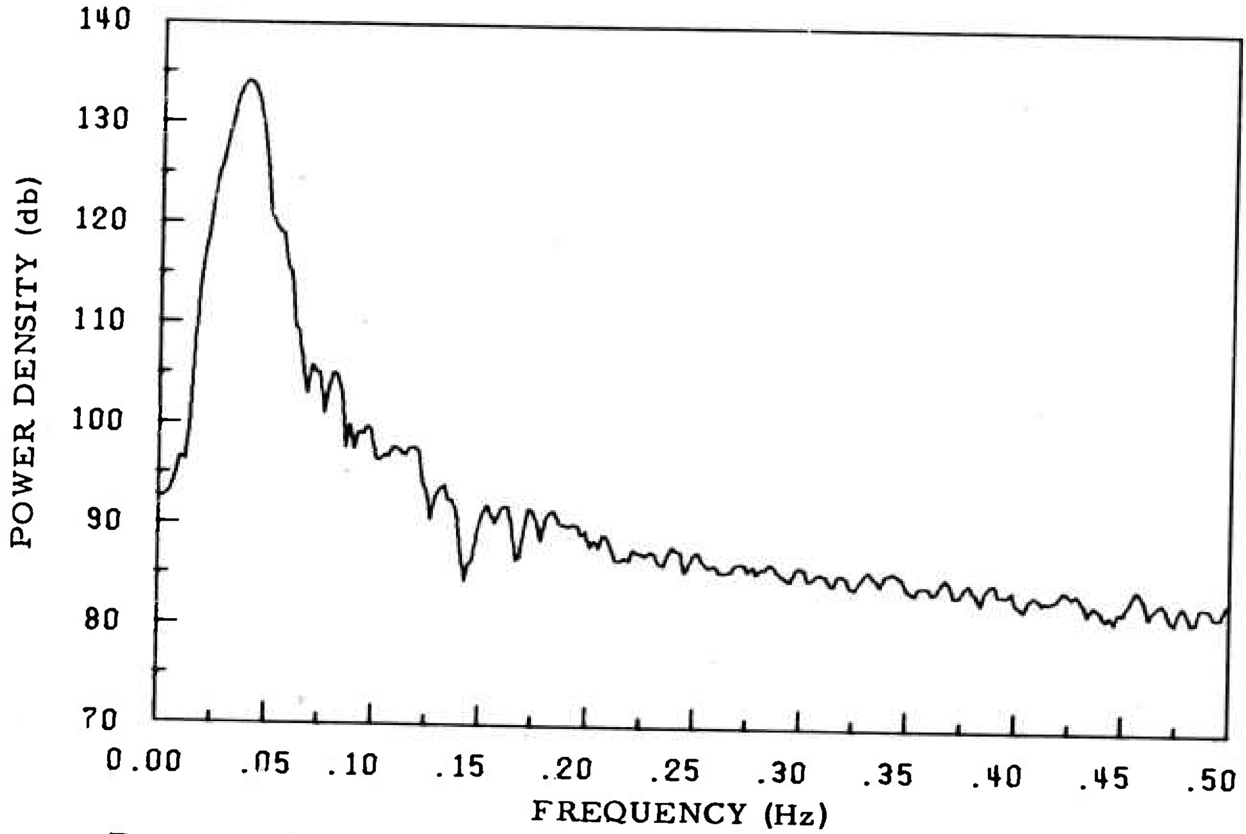

Figure III-7. Power Density Spectrum of Vertical Trace, Rat Island

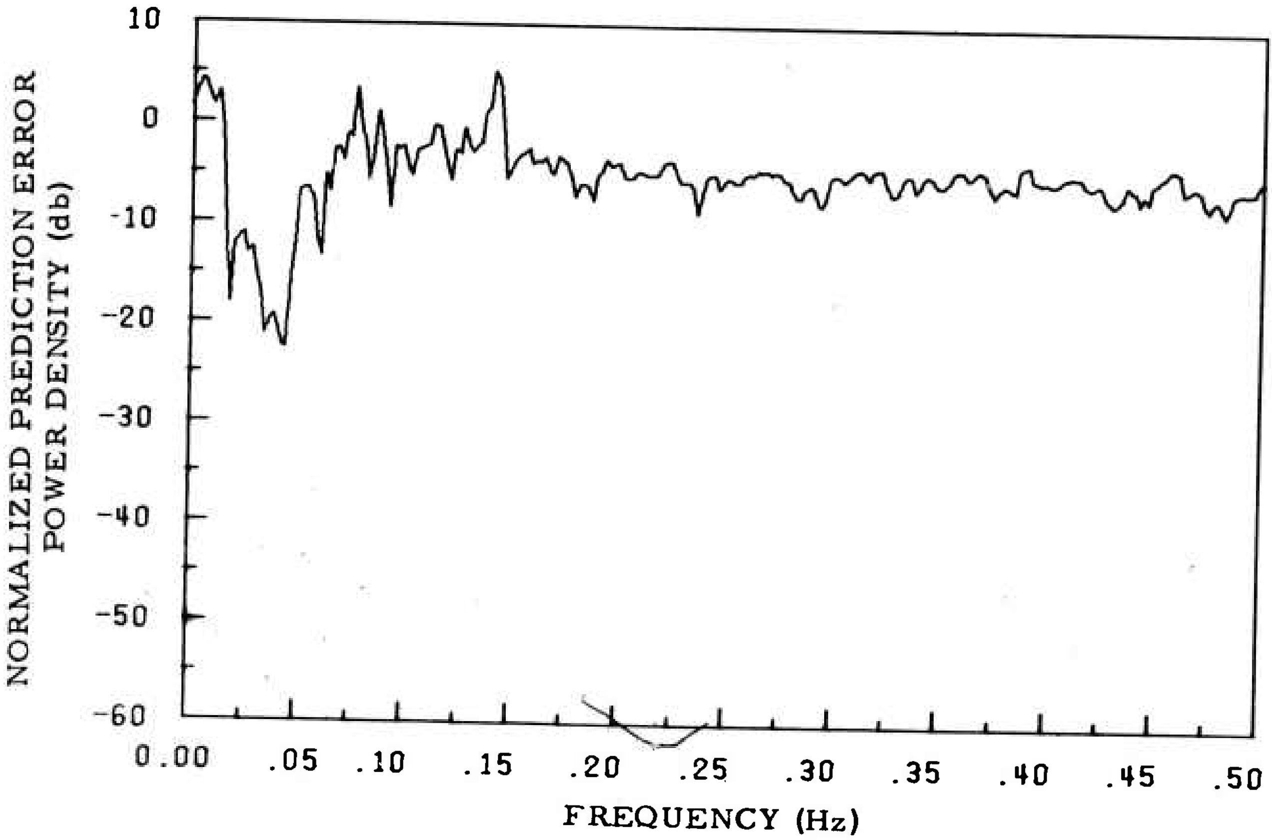

Figure III-8. Normalized Prediction Error Power Density Spectrum, Rat Island

SECTION IV

The following conclusions are based on the results discussed in the previous sections:

- The interfering event suppression increases as the interfering-to-target-event ratio increases. For the limiting case — when the target event is completely eliminated — the MCF can reduce the interfering event 22.07 db in the broadband sense, and the peak value interfering event suppression is about 34 db at 0.042 Hz. For target event 10 db down, the MCF can suppress the interfering event by only 15.53 db in the broadband sense and 24 db (at 0.037 Hz) for peak value interfering event suppression.
- The coherence between vertical and horizontal traces is not conclusive. The prediction error is -9.16 db for the Soloman Island event, and -16.43 db for the Rat Island event. The different prediction error may have been due to complications from scattering along the path. It is however, not clear what causes this phenomenon nor how great is the variability in horizontal-to-vertical component predictability. This data suggests that 3-component multichannel filtering techniques, which were previously not too successful at LASA, would again be of little help at UBO.

SECTION V

REFERENCES

1. Texas Instruments Incorporated, 1968: Long-Period Signal Separation, Large-Array Signal and Noise Analysis, Special Report No. 23, Contract AF33(657)-16678, 20 September.

2. Texas Instruments Incorporated, 1969: Multicomponent Long-Period Signal Separation, Advanced Array Research, Special Report No. 6, Contract F33657-68-C-0867, 28 April.

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Interfering event suppression coherence						